Vikram A Sarabhai Community Science Centre (VASCSC) is a pioneering institution in the field of science education, founded by Dr. Vikram Sarabhai in 1966. It was created as a facility where people concerned about the quality of science education could come together to try out new ideas and methods of teaching science and mathematics. Its mandate is to stimulate interest, encourage, and expose the principles of science and scientific method to the community and also improve and innovate various areas of science education. VASCSC has well-equipped laboratories in Biology, Chemistry, Physics, Mathematics, Electronics, Computers and Model Rocketry as well as Innovation Hub, Workshop, Library and Science Playground. It is open to everyone interested in exploring science and technology.

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WATER BOOSTER
MODEL ROCKETRY

Student Handbook

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WATER BOOSTER

MODEL ROCKETRY

Student Handbook

DEVELOPED BY
VIKRAM A SARABHAI COMMUNITY SCIENCE CENTRE
AHMEDABAD – 380 009

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Preface

The thrill and adventure of space exploration has not left many untouched. The success of space programmes has attracted the attention of many, especially young people, who desire to build rockets on their own. But, rocket fabrication requires training and a lot of care. Model rocketry is an activity which allows these young enthusiasts to fulfil their interest. Some years back, no facility, guidance or material was available for those wanting to pursue model rocketry. This led to the initiation of the 'Model Rocketry Lab' at Vikram A Sarabhai Community Science Centre (VASCSC). This activity was inspired by late Dr. Howard Galloway from USA, when he was working for the SITE project of Indian Space Research Organization (ISRO), Ahmedabad. Various training programs for teachers and students were offered every year in Model Rocketry.

Today, model rocketry is a popular activity of the Centre. Participants of this activity not only learn to build model rockets from easily available simple materials, but are also encouraged to experiment with their designs and come up with new ideas in rocket fabrication. This manual is a guide and will supplement the Model Rocketry Activity. The users will be able to fabricate water booster model rockets using this manual. They will also be able to experiment with the parts of model rockets and use their own imagination to construct them. Different aspects of model rocketry are covered in the chapters of this manual. VASCSC proposes to enhance its model rocketry activity, formulate a space education programme, and carry it to a large number of schools in the country. I hope the users will find it useful and in the future too, the Centre will be able to bring out such manuals for different categories of model rockets and nurture the enthusiasm of budding model rocketeers.

Dilip Surkar
Executive Director

❶ INTRODUCTION

1.1 Historical Overview

The invention of first true rockets was accidental. In the first century A.D., the Chinese reportedly had a simple form of gunpowder made up of saltpetre, sulphur and charcoal dust. They used this kind of gunpowder mostly for fireworks in the religious and other festive celebrations. To create explosions, they filled bamboo tubes with gunpowder and tossed them into fires. Some of those tubes failed to explode and instead skittered out of the fires, propelled by the gases and sparks produced from the burning gunpowder.

The Chinese began experimenting with gunpowder-filled tubes. At some point, they attached bamboo tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the exhausting gases. The true rocket was then born. The date reporting the first use of true rockets was in 1232. At this time, the Chinese and Mongols were at war with each other. During the battle of Kai-Keng, the Chinese repelled the Mongol invaders by a barrage of arrows of flying fire. These fire-arrows were a simple form of solid-propellant rockets. A tube, capped at one end, contained gunpowder. The other end was left open and the tube was attached to a long stick. When the powder ignited, the rapid burning of powder produced fire, smoke and gas that escaped out of the open end and produced a thrust. The stick acted as a simple guidance system that the rocket headed in one general direction as it flew through the air. How effective these arrows of flying fire were as weapons of destruction is not clear, but their psychological effects on the Mongols must have been formidable.

Following the battle of Kai - Keng, the Mongols produced rockets of their own and may have been responsible for the spread of rockets to Europe. By the 16th century rockets fell into a time of disuse as weapons of war, though they were still used for fireworks displays. A German fireworks maker, Johann Schmidlap, invented the step rocket, a multi-staged vehicle for lifting fireworks to higher altitudes. A large sky rocket (first stage) carried a smaller sky rocket (second stage). When the large rocket burned out, the smaller one continued to a higher altitude showering the sky with glowing cinders. Schmidlap's idea is basic to all rockets today that go into outer space.

Rockets in India

Chinese traders used to visit South Indian port of Quilon (now renamed as Kollam) and Arab traders used to visit northern Malabar region of Kerala especially for white pepper trade, and through them gunpowder might have reached India. The earliest known use of gunpowder in India was recorded in 1176-77 AD. During this period,

Benjamin of Tudela, Spain, visited Quilon and observed people worshiping the Sun. To symbolise the Sun they used Sun-Disc which rotated with a thunderous noise throwing fire sparks which indicated use of gunpowder. After 1400 AD, there are many references in Sanskrit literature, such as Agnichurna (gunpowder), Agnibana (rocket) and Agnikrida (fire works), for the use of gunpowder. Fire crackers known as chinna-bedi and chinna-padakkam were familiar words in the Malayalam literature which has several references to crackers. In 15th century various kinds of fireworks were displayed at Vijayanagar Kingdom during festivals.

The Mysore State further developed the gunpowder for rockets by using iron cyclinders. This change produced increased bursting pressure and also allowed the gunowder to be packed densely which resulted in greater thrust and range. These rockets had a range of about 1000 yards. It effectively used against the British.

▶ 1.2 Rocketry and Science

During 17th century, the great English physicist Sir Isaac Newton (1642-1727) laid the scientific foundation of modern rocketry. Newton organised his understanding of physical motion into three laws. These laws perfectly explain the motion of the rockets as well as working of the rockets in some specific medium and in vacuum. Newton's laws of motion gave a practical impact on design of rockets. In 1720, a Dutch professor, Willem Gravesande, built model cars propelled by steam jets. Rocket experimenters in Germany and Russia began working with rocket of mass more than 45 kg. Some of these rockets were so powerful that their escaping exhaust flames bored deep holes in the ground even before liftoff.

During the end of the 18th century and early into 19th century, rockets experienced a brief revival as a war-weapon. The success of Indian rocket barrages against the British in 1792 and again in 1799 caught the interest of Colonel William Congreve. He set out to design rockets for use by the British military. His rockets, the Congreve rockets, were very successful in battle. Even with his work, the accuracy with the rockets had not much improved from early days. The devastating nature of war rockets was not their accuracy or power; but their numbers. All over the world, rocket researchers experimented with ways to improve the accuracy of the rockets. An English man, William Hale developed a technique called spin stabilization. In this method, the escaping exhaust gases struck small vanes at the bottom of the rocket, causing it to spin much as a bullet does in flight. Many rockets still use variations of this principle today. Rocket use continued to be successful in battles all over the European continent.

▶ 1.3 Beginning of Modern Rocketry

In 1898, a Russian school teacher, Konstantin Tsiolkovsky (1857-1935) proposed an idea of space exploration by rocket. In a report published by him in 1903, he suggested the use of liquid propellants for rockets in order to achieve better performance. He stated that only exhaust velocity of escaping gases limited the speed and range of rockets. For his ideas, careful research and great vision, Tsiolkovsky has been called the father of modern astronautics.

Early in the 20th century, an American, Robert H. Goddard (1882-1945), conducted practical experiments in rocketry. He became interested in different ways of achieving higher altitudes than lighter-than-air balloons. He published a pamphlet in 1919 entitled 'A Method of Reaching Extreme Altitudes'. Today this mathematical analysis is very well applicable to meteorological sounding rockets. In the pamphlet, he reached to several conclusions important to rocketry. From his tests, he stated that a rocket operates with greater efficiency in a vacuum than in air. At the time, most people mistakenly believed that the presence of air was necessary for a rocket to push against. He also stated that multistage of step rockets were the answer to achieving high altitudes and that the velocity needed to escape Earth's gravity could be achieved in this way. His earliest experiments were with solid-propellant rockets. In 1915, he began to experiment with various types of solid fuels and to measure the exhaust velocities of burning gases. While working on solid-propellant rockets, he became convinced that a rocket could be propelled better by liquid fuel. No one had ever built a successful liquid-propellant rocket before. It was a much more difficult task than building solid-propellant rockets.

For liquid propellant rockets, fuel and oxygen tanks, turbines and combustion chambers would be needed. In spite of the difficulties, Goddard achieved the first successful flight with a liquid-propellant rocket on March 16, 1926. Fuelled by liquid oxygen and gasoline, the rocket flew for only two and a half seconds, climbed 12.5 metres and landed 56 metres away in a cabbage patch. By today's standards, the flight was unimpressive, but like the first powered airplane flight by Wright Brothers in 1903, Goddard's gasoline rocket became the forerunner of a whole new era in rocket flight. Goddard's experiments in liquid-propellant rockets continued for many years. His rockets grew bigger and flew higher. He developed a gyroscope system for flight control and a payload compartment for scientific instruments. Parachute recovery systems returned the rockets and instruments safely to the ground. We call Goddard the 'father of modern rocketry' for his achievements.

▶ 1.4 Model Rocketry: An Educational Tool

Model Rocketry has been evolving as an excellant educational tool for illustrating the 'Space Age' principles. By this, the students are getting exposure towards the space related fields. As a result of their unlimited possibilities, they can also be used in many educational situations. Launching, tracking, time measuring and recovery of the rocket provide an excellent opportunity for the students to experience success and develop a sense of pride in their accomplishment and apply some mathematics they have been studying. Concepts such as distance, velocity, acceleration, momentum, Newton's laws of motion and gravitation, aerodynamic forces like thrust, drag, lift and gravity, Bernoulli's principle, the elements of propulsion, etc. are easier to comprehend when they get involved in this activity.

Apart from enjoying the work, the children learn several aspects of rocket launching, projectile motion, thrust mechanism and stability in an informal manner.

The students can fabricate model rockets using inexpensive material like thick paper, adhesive and motors of Diwali Rockets. These rockets are preferred because they are harmless. Children can learn various aspects of designing the model rockets, the importance of fins, nosecone, stability, launching mechanism, etc. After achieving a certain degree of proficiency at constructing simple single stage model rockets, children may proceed to build double stage, triple stage, parachute and streamer rockets using Diwali Rockets and water booster rockets. Developed countries like United states, Canada, Australia etc have been much involved in the organization of promotion, development, education and advancement of amateur aerospace activities, particularly in model rocketry.

▶ 1.5 What is a Model Rocket?

A model rocket is a real, flying, small size model of an actual big scientific or military type rocket or missile. The main feature of the model rocket is that it is constructed from non-metallic, light weight materials. The motors used are non-metallic, self contained solid propellant motors which are ignited either by incense sticks or electrically. Thus these model rockets are safe, challenging, educational rockets for school-college students and lay public.

There are different categories of model rockets: One is solid propellant model rockets and other is water boosters. Water booster Model Rockets propel with water and air as fuel. In solid propellant model rockets there are different types such as Single Stage, Double Stage, Triple Stage, Parachute, Streamer, Clustered motored, etc. Single Stage Model Rockets are the simplest type of rockets. However these types of rockets have one fundamental feature in common that all of them work based on the Newton's three laws of motion. The third law of motion says "Any action on a body is counteracted with equal and opposite reaction" This opposite reaction is responsible to propel the rocket upward overcoming the earth's gravitational force and rocket's own weight.

Water Booster Rocketry

The water booster rocket is basically an inverted polyethylene terephthalate (PET) soft drink bottle filled with water under pressure by compressed air occupying the empty space in the bottle. Its mouth works as nozzle expelling the water under pressure. The momentum of water jet from the nozzle is the action which creates reaction in opposite direction which becomes the upward thrust propelling the rocket when the bottle rocket is kept upright (fig-01). The main feature of the model rocket is that it is constructed using non -metallic, light weight materials available abundantly and easily. These rockets are useful in understanding the principles of rocket motion. Thus these model rockets are safe, fun filled educational tools for school-college students.

The construction of water booster rockets is very simple and can easily be understood by the school students. It uses low cost materials like waste soft drink PET bottles, card paper and thin plastic sheets etc. In fact, use of waste soft drink bottles as the main construction material supports the cause of harnessing green environment. It is said so, since waste bottles which otherwise would have added to the litters on road, are meaningfully used for making model rockets and demonstrating the science principles to the school students. This manual deals with only the water booster rockets.

▸ 2.1 Rocketry and Newton's Law of Motion

All the rocket motors operate under three very basic rules. These rules are commonly known as Newton's laws of motion. These rules were given by an English Physicist Sir Isaac Newton in 1687. Here these laws are given in very basic form. Objects at rest will stay at rest and objects in motion will continue the state of motion in a straight line unless acted upon by an unbalanced external force. Force is equal to mass times acceleration. For every action there is always an opposite and equal reaction. All these three laws are very simple to understand how things really move. But using them, precise determinations of rocket performance can be made.

▸ 2.2 Newton's First Law of Motion

The statement of the first law is very obvious, but to know its meaning in a real sense it is very necessary to understand the meaning of physical terms rest, motion and unbalanced force. Rest and motion can be thought of as being opposite to each other. Rest is the state of an object when it is not changing its position with respect to its surroundings. If you are sitting in a still chair, you can be said to be at rest. This term, however, is totally relative. The chair may actually be one of many seats on a speeding airplane. The important thing here to remember is that you are not moving with respect to your immediate surroundings. If rest were defined as a total absence of motion, it would not exist in nature. Even if you were sitting in your chair at home, you would still be moving because your chair is actually sitting on the surface of a spinning planet (the Earth) that is orbiting a star (the Sun). The star is moving through a rotating galaxy (the Milky Way) that is, itself moving through the Universe. While sitting still, you are in fact, travelling at a speed of hundreds of kilometres per second. Motion is also a relative term.

A rocket blasting off the launch pad changes from a state of rest to a state of motion. The third important term to understand is unbalanced force. If you hold a ball in your hand and keep it still, the ball is at rest. All the time the ball is held there though, it is being acted upon by forces. The force of gravity is trying to pull the ball downward, while at the same time your hand is pushing against the ball to hold it up. The forces acting on the ball are balanced. Let the ball go, or move your hand upward, the forces become unbalanced. The ball then changes from a state of rest to a state of motion.

In rocket flight, forces become balanced and unbalanced all the time. A rocket on the launch pad is balanced. The surface of the pad pushes the rocket up while gravity tries to pull it down. As the motors are ignited, the thrust from the rocket unbalances

the forces, and the rocket travels upward. Later, when the fuel inside the rocket is completely exhausted, it slows down, stops momentarily at the highest point of its flight, and then falls back to the Earth.

▸ 2.3 Newton's Third Law of Motion

For the time being, we will skip the second law and go directly to the third. This law states that every action has an equal and opposite reaction. If you have ever stepped off a small boat that has not been properly tied to a pier, you will know exactly what this law means. A rocket can lift off from a launch pad only when it expels gas out of its motor. The rocket pushes on the gas, and the gas, in turn, pushes on the rocket.

In rockets, the action is the expelling of gas out of the motor. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action or thrust from the motor must be greater than the weight of the rocket. While on the pad, the weight of the rocket is balanced by the force of the ground pushing against it. Small amounts of thrust result in less force required by the ground to keep the rocket in balance. Only when the thrust is greater than the weight of the rocket does the force become unbalanced and the rocket lifts off. In space, where unbalanced force is used to maintain the orbit, even tiny thrusts will cause a change in the unbalanced force which results change of speed or direction of the rocket.

One of the most commonly asked questions about rockets is how they can work in space, where there is no air for them to push against. The answer to this question can be given from the third law. Imagine the skateboard again. On the ground, the only part air plays in the motions of the rider and the skateboard is to slow them down. Moving through the air causes friction which is known as a drag. The surrounding air impedes the action-reaction. As a result, rockets actually work better in space than they do in air. As the exhaust gas leaves the rocket motor it must push away the surrounding air; this uses up some of the energy of the rocket. In space, the exhaust gases can escape freely.

▸ 2.4 Newton's Second Law of Motion

This law of motion is essentially a statement of a mathematical equation. The three terms of the equation are mass (m), acceleration (a), and force (F), the equation can be written as,

$F=ma$ (The equation reads: force equals mass times acceleration.)

To explain this law, we will use the example of cannon. When the cannon is fired, an explosion propels a cannon ball out of the open end of the barrel. It flies to its target. At the same time, the cannon itself is pushed backwards. This is action and reaction at work (third law). The force acting on the cannon and the ball is the same. What happens to the cannon and the ball is determined by the second law.

$$F = m\,(\text{cannon})\; a\,(\text{cannon})$$
$$F = m\,(\text{ball})\; a\,(\text{ball})$$

The first equation refers to the cannon and the second to the cannon ball. In the first equation, the mass is of the cannon itself and the acceleration is the movement of the cannon. In the second equation, the mass is the cannon ball and the acceleration is its movement. Because of the force (exploding gunpowder) is the same for the two equations,

Which can be represented as follows.

$m\,(\text{cannon})\; a\,(\text{cannon}) = m\,(\text{ball})\; a\,(\text{ball})$

In order to keep two sides of equations equal, the acceleration vary with mass. In other words, the cannon have a large mass and a small acceleration, while the cannon ball has a small mass and a large acceleration.

Apply this principle to understand the motion of the rocket. Replace the mass of the cannon ball with the mass of the gases being ejected out of the rocket motor. Replace the mass of the cannon with the mass of the rocket moving in other direction. Force is the pressure created by the controlled explosion taking place inside the rocket's motors. That pressure accelerates the gas one way and rocket the other.

Some interesting things happen with rockets that do not happen with the cannon and ball in this example. With the cannon and cannon ball, the thrust lasts for just a moment. The thrust for the rocket continues as long as its motors are firing. Furthermore, the mass of the rocket changes during flight. Its mass is the sum of all its parts. A rocket's parts include motors, propellant tanks, payload, control system and propellants. By far, the largest part of the rocket's mass is its propellants. But, that amount constantly changes as the motors fire. It means that rocket's mass gets smaller during flight. For the left hand side of the equation to remain in balance with right hand side, acceleration of the rocket has to increase as its mass decreases. That is why a rocket starts off moving slowly and goes faster and faster as it moves into space.

Newton's second law is especially useful while designing efficient rockets. To enable a rocket to climb into Low Earth Orbit (LEO), it is necessary to achieve a speed, in excess of 7.78 km/s. A speed of over 11.2 km/s, called escape velocity, enables a rocket to leave the Earth and travel out into deep space. Attaining space flight speeds requires the rocket motor to achieve the greatest action force possible in the shortest time. In other words, the motor must burn a large mass of fuel and push the resulting gas out of the motor as rapidly as possible. Newton's second law can be restated as follows: the greater the mass of rocket fuel burned, and the faster the gas produced can escape the motor, the greater the thrust of the rocket.

Momentum and Newton's Second Law of Motion

If an object is moving with uniform velocity, a force is required to change its speed and direction. This statement can easily be recognised by Newton's first law of motion. Linear momentum (P) is defined by mass of the object (m) multiplied with its velocity(u). i.e. $P = mu$

From this equation, we can say that the object's momentum can be increased by either increasing mass or velocity. Non-relativistically, mass is an invariant quantity for a given object that means momentum of the object can be changed by changing its velocity.

Changing an object's momentum is very important aspect in rocketry. The change in momentum means that over some period of time, either its mass is changed or its velocity is unchanged. The nozzle of the rocket motor, then, must be designed for a particular operating pressure range, such as vacuum conditions (as the space shuttle main engines) or for sea level conditions (as a model rocket motor). When the nozzle reaches its designed altitude operating pressure, the second term in the thrust equation drops off completely, and the thrust produced is equal to the momentum term:

$F = dm/dt * v$

Here we have made assumption that model rocket engines should be designed to operate at sea level atmospheric pressure conditions. This is not a bad assumption because for most of the model rocket motors, the entire burning occurs at low altitudes. These motors cannot be used for outer space. Under one of the assumptions we made, a model rocket motor should have a constant thrust over its entire burn period. But, as we all know, almost all motors available in market have a high initial

liftoff thrust and then it levels off. This does not mean our equations are wrong, it means that the assumptions that we made were wrong. The mass flow of propellant can change over the duration of the rocket burn, but the thrust equation is still valid as long as we take very short periods of time where it can be assumed that $d\tau/dt=$ constant

▶ 2.5 Considering Newton's Three Laws of Motion Together

If we are considering three laws of motion together, will get an idea about how rockets are working. A force must be exerted for a rocket to lift off from a launch pad or for a craft in space to change speed or direction (First Law). The amount of thrust (force) produced by a rocket motor will be determined by the rate at which the mass of the rocket fuel burns and the speed of the gas escaping the rocket (Second Law). The reaction or motion of the rocket is equal to and in opposite direction of the action or thrust from the motor (Third Law).

❸ FABRICATION OF WATER BOOSTER MODEL ROCKET

▶ 3.1 Components of a Water Booster Model Rocket

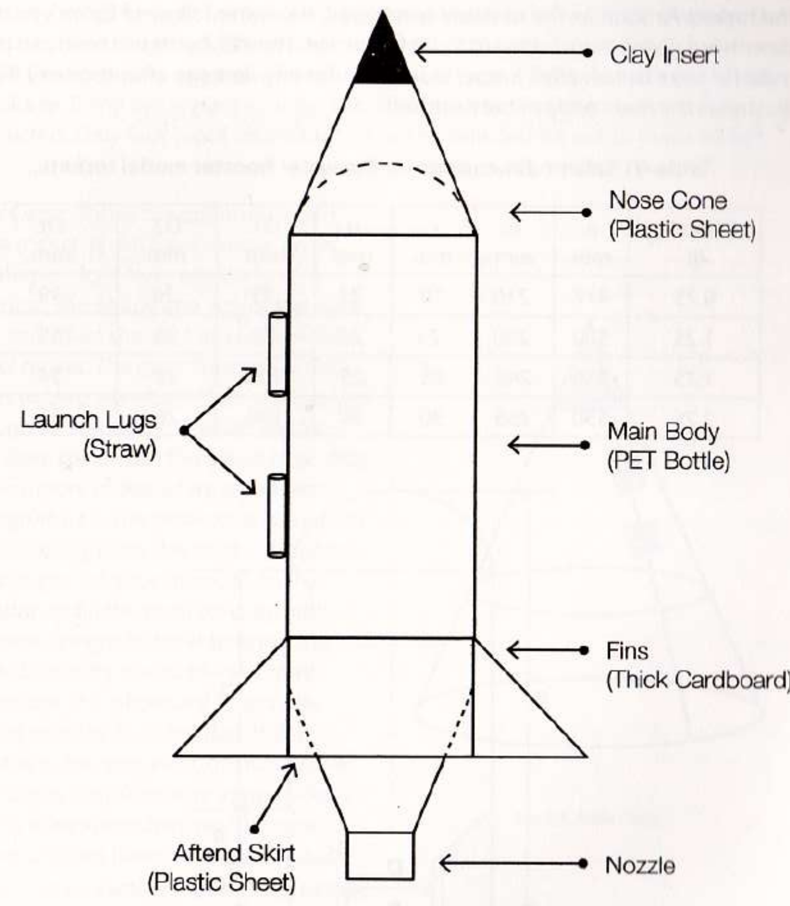


Fig-01. Water Booster Model Rocket

Main Body: It makes use of an empty PET water bottle as the main body of the rocket. The bottle is mounted upside down. In this condition, the mouth of the bottle acts as the nozzle of the rocket. The upward bottom acts as the fore end on which nose cone gets mounted. The cylindrical portion of the bottle is used to fill water and air under pressure through its nozzle. Under this condition, it acts as a power house for the rocket. As soon as the pressure is released, the water followed by air ejects out downward giving thrust upward to lift the rocket. The PET bottles so used can be re-used for next launch after proper inspection for any damage after recovery. Fig-02 illustrates the main body of bottle rocket.

Table-01 Salient dimensions for the water booster model rockets.

Capacity lit	a mm	b mm	c mm	d mm	D1 mm	D2 mm	Dt mm
0.75	417	210	19	23	73	26	39
1.25	500	220	25	25	85	26	45
1.75	530	240	35	25	100	26	54
2.25	550	265	30	30	108	26	55

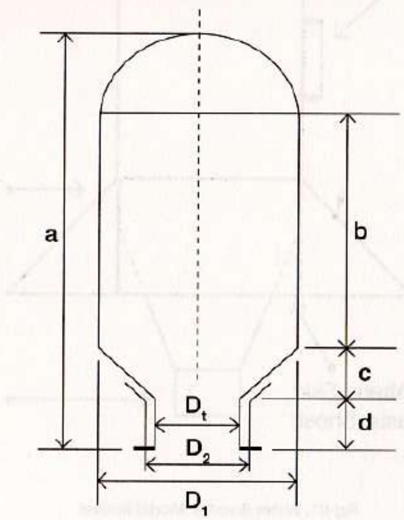


Fig-02. Main Body (All dimensions in mm)

Preparing The Main Rocket Body

Material required

1. Inspect the bottles for visual damages. Reject the bottle with any defects, crushes and mutilation.
2. Clean the bottle thoroughly with detergent powder solution. After cleaning, the bottle should be clearly transparent.
3. Test the bottles for any leaks. Pressurize the bottle to 10 psi pressure and check leakage, if any by dipping in water tub. If bubbles appear, the bottle shall be rejected. Only leak proof tested bottles will be selected for use to make rocket.

Nose Cone: This is the uppermost part of the rocket. It can have various types and shapes right from conical to semi-spherical. The Shape and size of the nose cone can affect the performance of the model rocket. The main function of this part is to help penetrate the model rocket through air smoothly. In other words, nose cone minimizes the effect of air drag on the model rocket while penetrating through the air. The nose cone is coupled with the body tube. It is made of a plastic sheet as per the procedure. It also has provision to fill the nose cone tip with a dummy weight in order to bring the centre of gravity ahead of the centre of pressure. It is necessary to provide desired stability to the rocket. If the rocket is to be recovered, the nose cone also houses the parachute system along with its release mechanism. There are two nose cones have to be used in each rocket. The procedure is described below.

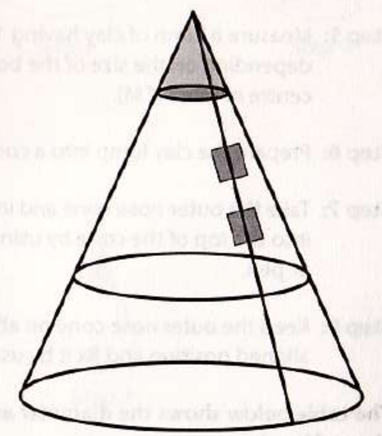


Fig-03. Nose Cone

Making Nose Cone

Inner nose cone

Step 1: Take a plastic sheet/OHP sheet of length (l) and breadth (b) having 34 and 17 cm respectively. Using a semicircular template, make a semicircle and mark the lines as shown in the figure-4.

Step 2: Fold the semicircular sheet into a cone as shown in the figure and stick the end portion by using an adhesive tape.

Outer nose cone

Step 3: Take a plastic sheet. By using semi circular template, make a semicircle

Step 4: Fold the semicircular sheet into a cone shaped structure as shown in the figure and stick the end portion by using an adhesive tape. Make sure that the base diameter of the cone should be smaller than the inner one.

Step 5: Measure a lump of clay having 10-20 gram. The weight of the clay lump is depending on the size of the bottles. This is to provide the balance at the centre of mass (CM).

Step 6: Prepare the clay lump into a cone shape.

Step 7: Take the outer nose cone and insert the clay into the cone. Push the clay into the top of the cone by using rod diameter (2cm) small cylindrical or pen.

Step 8: Keep the outer nose cone on above the inner nose cone in a vertically aligned position and fix it by using an adhesive tape.

The table below shows the diameter and radius of the nose cone for different sizes of bottle

Bottle size (L)	Diameter (D in cm)	Radius (r in cm)
0.75	26	13
1.25	34	17
1.75	34	17
2.25	34	17

The nose cone is ready!

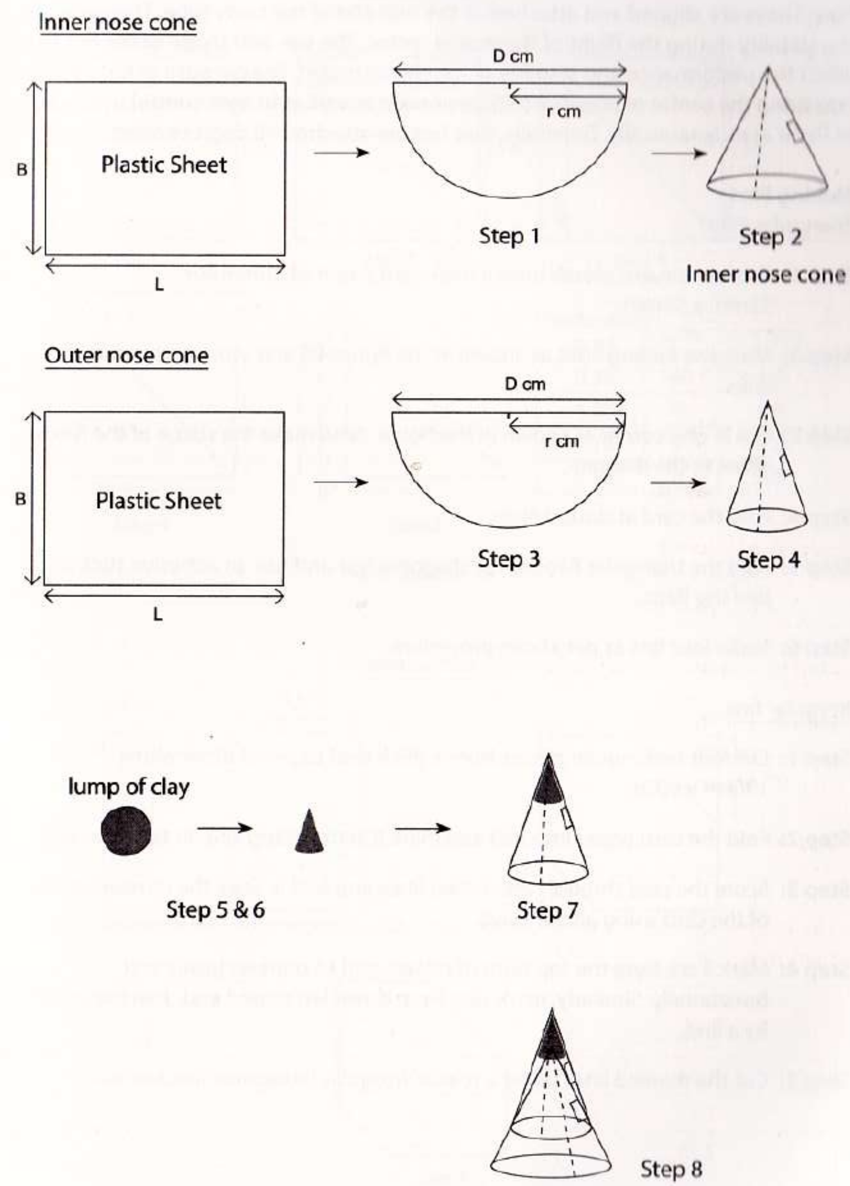


Fig-04. Nose Cone

Fins: These are aligned and attached at the rear end of the body tube. They provide the stability during the flight of the model rocket. The size and shape of the fins can affect the performance and stability of the model rocket. The purpose of fins (fig-05) is to bring the centre of pressure (CP) downward as well as to auto control the course of flight aerodynamically. Generally, four fins are attached 90 degrees apart.

Making Fins

Triangular Fins

Step 1: Cut four square pieces from a thick card paper of dimension 55mm x 55mm.

Step 2: Mark the folding lines as shown in the figure-05 and score at the dotted lines.

Step 3: Cut in one corner as shown in the figure. Now make the shape of the fins as given in the diagram.

Step 4: Fold the card at dotted lines.

Step 5: Fold the triangular flaps at the diagonal line and use an adhesive stick to join the flaps.

Step 6: Make four fins as per above procedure.

Irregular fins

Step 1: Cut four rectangular pieces from a thick card paper of dimensions 130cm x 60cm.

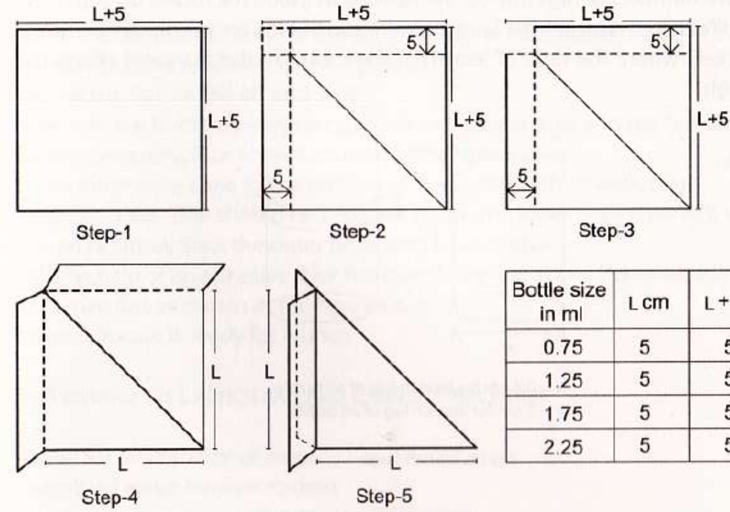
Step 2: Fold the card paper into half and mark 0.5cm folding line on both the sides.

Step 3: Score the card through the dotted lines and fold it. Stick the remaining area of the card using an adhesive.

Step 4: Mark 3 cm from the top right of closed-end to both vertically and horizontally. Similarly, mark 1cm from down left closed end. Join the points by a line.

Step 5: Cut the marked lines using a scissor. Irregular hexagonal fins are ready.

Triangular fins



Bottle size in ml	L cm	L + 5cm
0.75	5	5.5
1.25	5	5.5
1.75	5	5.5
2.25	5	5.5

Fig-05. Making Fins

Irregular fins

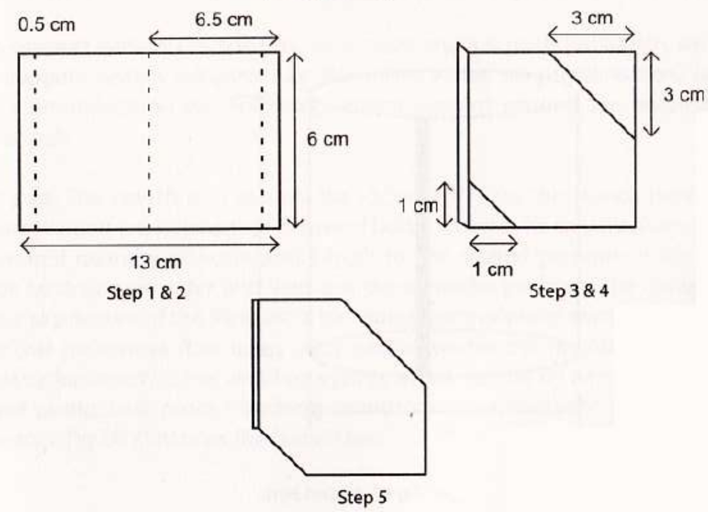
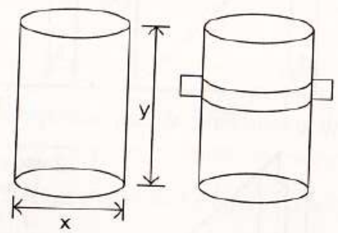


Fig-5.1 Making Fins

Launch Lugs: These are the cylindrical sleeves fixed on the rocket body parallel to its axis. Two numbers of lugs (fig-06) are needed to guide the rocket during an initial phase of lift and to clear off the launch pad. Launch lugs are primarily necessary for those rockets where the ratio of length of the rocket to the diameter of the rocket ratio is high.



x = 0.8 cm for launch lug of all bottle
y = 3 cm for launch lug of all bottle

Fig-06. launch Lugs

Aft End Skirt: To increase the cylindrical length of the main body, a skirt is added as shown in fig-07. The diameter of this skirt is same as that of the main body. Length is 5 cm. It is also made of a plastic sheet.

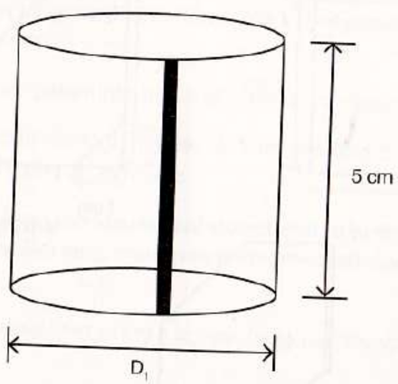


Fig-07. Aft End Skirt.

▸ 3.2 Assembly of Water Booster Model Rocket

1. Take a checked bottle and Fix the Aft end skirt on the bottom side of the bottle with an adhesive as shown in the figure-07.
2. Then fix the fins on the aft end skirt.
3. Make sure the bottle opening is nozzle facing downwards and the fins are equally spaced. Generally, four fins are attached 90 degrees apart.
4. Fix the inner nose cone to the bottom of the bottle with an adhesive.
5. The outer nose cone should be kept just above the inner nose cone in a vertically aligned position. Stick the outer nose with an adhesive.
6. With the help of an adhesive stick the launch lug just above the middle line of any of the two fins as shown in the figure-06.
7. Now, the rocket is ready for launch.

▸ 3.3 Assembly on Launch pad and Launch Procedure

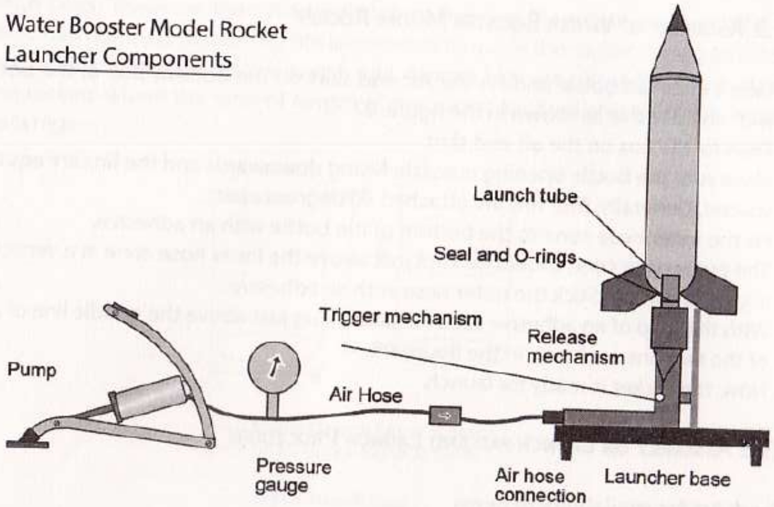
Check list for availability of items

1. Assembled water booster rockets
2. Launch pad complete with release mechanism
3. Source of water
4. Source of compressed air (Air pump)
5. Inclinometer, stop watch and video camera
6. Measuring tape

Launch support system: Once the rocket is made and it is ready for launch, we need launch support system infrastructure like filling water, air pressurisation, launch release, instrumentation etc. Following launch support systems are necessary to enable launch

Launch pad: The launch pad secures the rocket firmly on the launch pedestal in desired inclination (usually vertical in case of bottle rockets). Its construction enables filling desired quantity of water and fills air to the desired pressure. It has safety provision to drain out water and vent out the air under pressure. The system also displays the pressure of the filled air. It has Non-return valves in water and air filling lines so that no reverse flow takes place and to enable the retention of pressure when ready for launch. It has air filling system which may be by a compressor or by cycle foot pump. Leak proof Plumbing connects various hydraulic and pneumatic components. Fig-08 illustrates the launch pad.

Water Booster Model Rocket Launcher Components



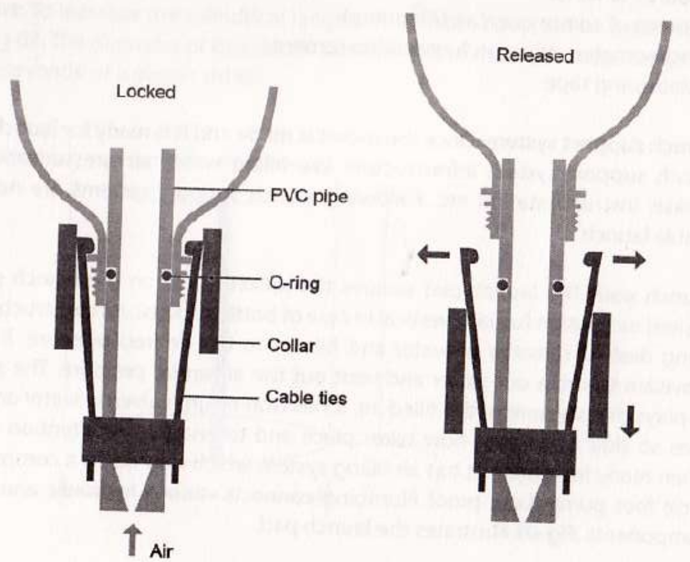


Fig-08. Launch pad system

Inclinometer

Inclinometer is used necessary to measure the maximum altitude the rocket achieves. A clinometers or inclinometer is an instrument for measuring angles of slope (or tilt), elevation or depression of an object with respect to gravity. It is also known as a tilt meter, tilt indicator, slope alert, slope gauge, gradient meter, gradiometer, level gauge, level meter, declinometer, and pitch & roll indicator. Usually an inclinometer is used to measure the elevation angle of the rocket at peak altitude (apogee). It is a manual process and much depends on the skill of the observer to capture the flying object continuously. Hence manual errors can vary from person to person.

Material requried: Protractor (180°), a thick card board or Wooden Base, scissor, scale, pencil, push pin, nut, thread, cello tape

Making Inclinometer

- Make a small hole in the centre of the given protractor (180°).
- After this, take a scale and stick it to the protractor near the base line side.
- Now attach one end of the thread to the sharp nail of the push pin and the other end to the nut.
- Insert the push pin with thread through the hole of the protractor one end of the pencil such that the nut with the thread can hang freely parallel to the plane of pencil.
- Now take a hard card board or a wooden base and make a hole at centre.
- Insert another part of the pencil into the hole at centre.
- You are ready with your inclinometer. Now you take the observations of angles and calculate the height for the different stars.

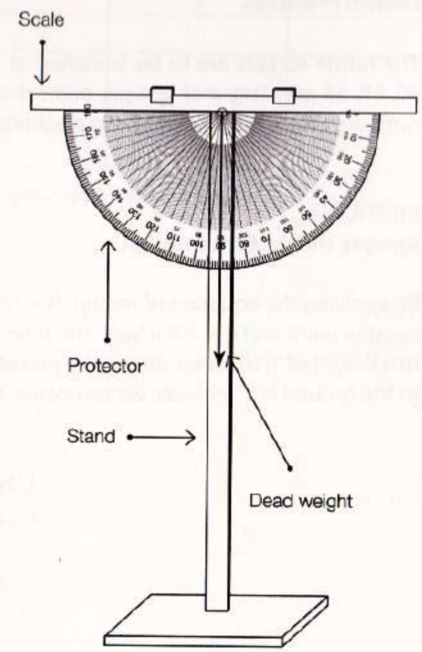


Fig-09. Inclinometer

Mounting Water Booster Rocket on Launch Pad

1. Mount the nozzle of the rocket onto the nipple/adopter of the launch pad in such a way that it is visually vertical. Apply water proof grease onto the o-rings before assembly. Push the bottle nozzle down on to the launch adopter so that both the o-rings are inside the nozzle. Make sure the fins do not get damaged.
2. Ensure the launch lugs (If provided) are free for rocket movement
3. Ensure air filling and pressurization system are stand-by
4. Ensure all the crews are in place
   - Video person with video camera
   - Person on inclinometer
   - Person to measure time
   - Person to pressurise the bottle, give count down and release.

3.4. Test And Measurement Plan

Launch Pressures

The bottle rockets are to be launched at following pressures in the bottle 20, 30, 40, 50, 60 psi. Height of apogee point should be computed corresponding to each pressure as per the following two methods and tabulated as per the table given.

METHOD-I
Apogee Height Computation

By applying the equation of motion $h = 1/2\ gt^2$ Where t is the time of fall from the apogee point and g is $9.8 m/sec^2$. The time 't' is observed stop watch method. It rises to a height of 'h' in meter during the powered flight. If the free fall time from apogee to the ground is 't' seconds, we can derive the altitude by the following equation.

$h = 1/2gt^2$
Here $g = 9.8\ m/s^2$

Pressure psi	Time to fall from apogee (stop watch) T_1 sec	Time to fall from apogee (stop watch) T_2 sec	Average Time T_{av} sec	Apogee height $h = 1/2gt^2$ m
40				
50				
60				
70				

METHOD-II
Inclinometer Method

If the distance of the observer at inclinometer from launch pad is 'd' in meter and inclination angle of the apogee point measured is α then the height is $h = d \tan\alpha$

Pressure psi	Inclinometer angle (α_1)	Inclinometer angle (α_2)	Average angle $\alpha = \frac{\alpha_1 + \alpha_2}{2}$	Apogee height $h = h_1 + d \tan\alpha$ (meter)
40				
50				
60				
70				

Height from ground to inclinometer's protector h_1 = ... m

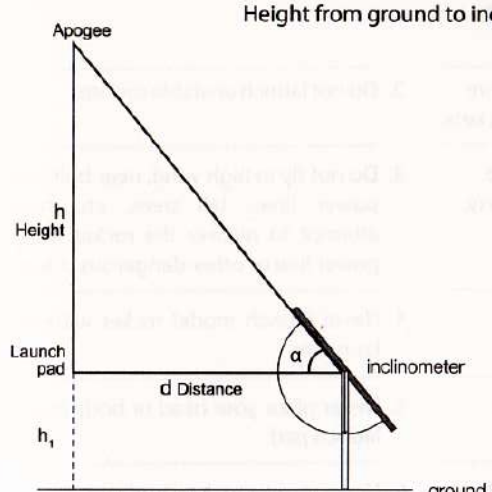


Fig -10 Inclinometer Method

ANNEXURE-1

Safety Procedures

1. Launch release mechanism should be locked properly before starting pressurisation.
2. If there are any leaks during leak check, it should be sealed before proceeding further with the pressurisation operations.
3. The students should not lean directly over the rocket during pressurisation.
4. The distance of pressurisation equipments should preferably be about 10 ft away from the launch pad.
5. If the rocket does not get released on release command, nobody should go near the rocket unless the rocket is totally de-pressurised by opening air relief valve.
6. In such case necessary corrective actions are to be taken before the next launch.

Do's	**Don'ts**
1. For construction of model rocket, use light weight material e.g.PET bottle, cardboard, plastic sheet, clay, etc.	1. Do not use metal in construction part. The model should not exceed 450 gm.
2. Test stability of the model before launching it. Fly only stable rockets.	2. Do not launch unstable rockets.
3. Fly the model in open area free from people and public property.	3. Do not fly in high wind, near buildings, power lines, tall trees, etc. Never attempt to recover the rocket from a power line or other dangerous places.
4. Launch a model rocket from a launcher.	4. Never launch model rocket without a launcher.
5. Keep the tracker along the eye level.	5. Never place your head or body over the launch pad.
6. Keep the launching device vertical.	6. Never project rockets horizontally which are bound to cause accidents.

ANNEXURE-2

Web Resources

1. Model Rocketry Program – USA: www.nar.org
2. Model Rocketry in Australia: www.rocketry.org.au
3. Canadian Association of Rocketry – CAR: www.canadianrocketry.org
4. Model Rocketry in New Zealand: www.nzrocketry.org.nz
5. Model Rocketry in UK: www.ukra.org.uk
6. Model Rocketry in Germany: www.modellraketen-muenchen.de
7. Model Rocketry in Europe: www.europerocketry.com

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ISBN: 1-85486-229-4

VAN MILLIGAN, Timothy S
Model Rocket Design and Construction 2nd Edition
Publisher: Kalmbach Books
ISBN: 096536201-9

VAN MILLIGAN, Timothy S
Model Rocket Design and Construction 3rd Edition
Publisher: Kalmbach Books
ISBN: 13:978-0-9653620-2-3

Rockets- A Teachers Guide with Activities in Science, Mathematics and Technology
Publisher: National Aeronautics and Space Administration

Model Rocketry - A Communicators' Guide
Model Rocketry Lab, VASCSC, 2011.

Model Rocketry - A Student Manual
Model Rocketry Lab, VASCSC, 2011.

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